EVALUATION OF n + 14N CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

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7 August 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.3 (Release 3) evaluation by P. G. Young, G. M. Hale, and M. B. Chadwick [Yo94].

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 3 evaluation of n + 14N data extends to 40 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file, and we have only included the ENDF/B-VI data below 20 MeV. No essential data for applications is lost with our$ representation above 20 MeV.   8

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

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MF=3 MT=  1   Total Cross Section
     MT=  2   Elastic Scattering Cross Section
     MT=  3   Nonelastic Cross Section
     MT=  5   Sum of Binary (n,n') and (n,x) Reactions

MF=4 MT=  2   Elastic Angular Distributions

MF=6 MT=  5   Production Cross Sections and Energy-Angle
              Distributions for Emission Neutrons, Protons,
              Deuterons, Tritons, and Alphas; and Angle-
              Integrated Spectra for Gamma Rays and Residual
              Nuclei That Are Stable Against Particle Emission
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The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + N14 and p + N14 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE n + N-14 ANALYSIS

GNASH calculations [Yo92,Ch94] were performed for neutron and proton reactions on nitrogen up to 150 MeV, and the calculated results were benchmarked against experimental data. For neutrons below 100 MeV, the present evaluation made extensive use of our previous work [Ch96a]. Very minor differences with this earlier work exist due to recent developments in the GNASH code. Much use was made of measured data in the evaluation, since an accurate modeling of reactions on a light nucleus is difficult. In this way we were able to obtain a fairly good description of the emission spectra of secondary particles and gamma rays. Additionally, the (angle-integrated) emission spectra of heavy recoils were calculated using our model described in Ref. [Ch96]. Some additional information on this evaluation can be found in Ref. [Ch97].

Between 20 and 150 MeV, the optical models used (the neutron potential of Islam below 60 MeV [Is88]; Madland's potential [Ma88] at higher energies, with Lane transformations for the proton potential) provided a reasonably good description of measured reaction cross section data. But since a very accurate description of the reaction cross section is important for determining secondary particle spectra, we slightly modify the calculated results to better describe the experimental data, and renormalize the calculated transmission coefficients accordingly. The SCAT2 code [Be92] was used to calculate the transmission coefficients. No measurements for the neutron reaction cross section on nitrogen exist above about 50 MeV. However, systematics have been determined from a number of target elements at 95 MeV by DeJuren [De50], and for 100 MeV protons by Kirby and Link [Ki66] (at this energy the proton and neutron reaction cross sections would be expected to be very similar). We have, therefore, used these systematics to guide our evaluated reaction cross sections. Additionally, below 50 MeV we have also been guided by the proton-induced reaction cross sections of Carlson et al. [Ca75]. Experimental total elastic scattering values of Islam et al. [Is88], Olsson et al. [Ol90], and Petler et al. [Pe85] were obtained by subtracting their angle-integrated elastic data from the evaluated total cross sections (see below).
The evaluated total cross section was obtained by slightly modifying the optical model results to agree with data, principally the new high-accuracy results of Finlay et al. [Fi93].

We use the ENDF/B-VI total cross section below 40 MeV recently evaluated by Young [Yo94].

Preequilibrium spectra for incident energies below 100 MeV were taken from our previous work [Ch96], where they were evaluated from a combination of FKK calculations [Ch93], and measured emission spectra data, whilst ensuring that unitarity is conserved (i.e., making sure the sum of primary emitted preequilibrium spectra does not exceed the reaction cross section). This approach has the advantage of facilitating a good representation of emission spectra experimental data. However, the lack of such data above 100 MeV prohibits its extension to higher energies, and therefore above 100 MeV, exciton model calculations were utilized from the GNASH code [Ka77, Ka85]. This results in some (small) discontinuities around 100 MeV in the production cross sections, though the impact of this is negligible for most applications.

Nuclear level densities were determined using the Ignatyuk model [Ig75], as implemented by Arthur et al. [Yo92]. Pairing energies were obtained from the Cook systematics with the Los Alamos extensions to light nuclei from [Ar83]. This continuum level density formulation is matched continuously onto discrete low-lying levels at the lower excitation energies. Discrete level information (energy, spin, parity, gamma-ray branching ratios) is tabulated for each nuclide in an input file, which is based on the Ajzenberg-Selove compilations. For each nucleus we performed a level-density analysis and determined the excitation energy at which we judged the level data complete. Gamma-ray transmission coefficients were obtained from the Kopecky-Uhl model [Ko92].

An important test of the accuracy of the data libraries is that the evaluated emission spectra of light particles (A < 5) should be consistent with the measurements by Subramanian et al. of UC-Davis [Su86]. We have compared our calculated (lab frame) angle-integrated emission spectra of protons, deuterons, and alphas, with these measurements, with good agreement. The structure seen at high emission energies is due to the inclusion of discrete nuclear levels in our calculations. Also, kerma factors obtained from the evaluated cross sections are in fairly good agreement with experimental data [Ch96].

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   1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:
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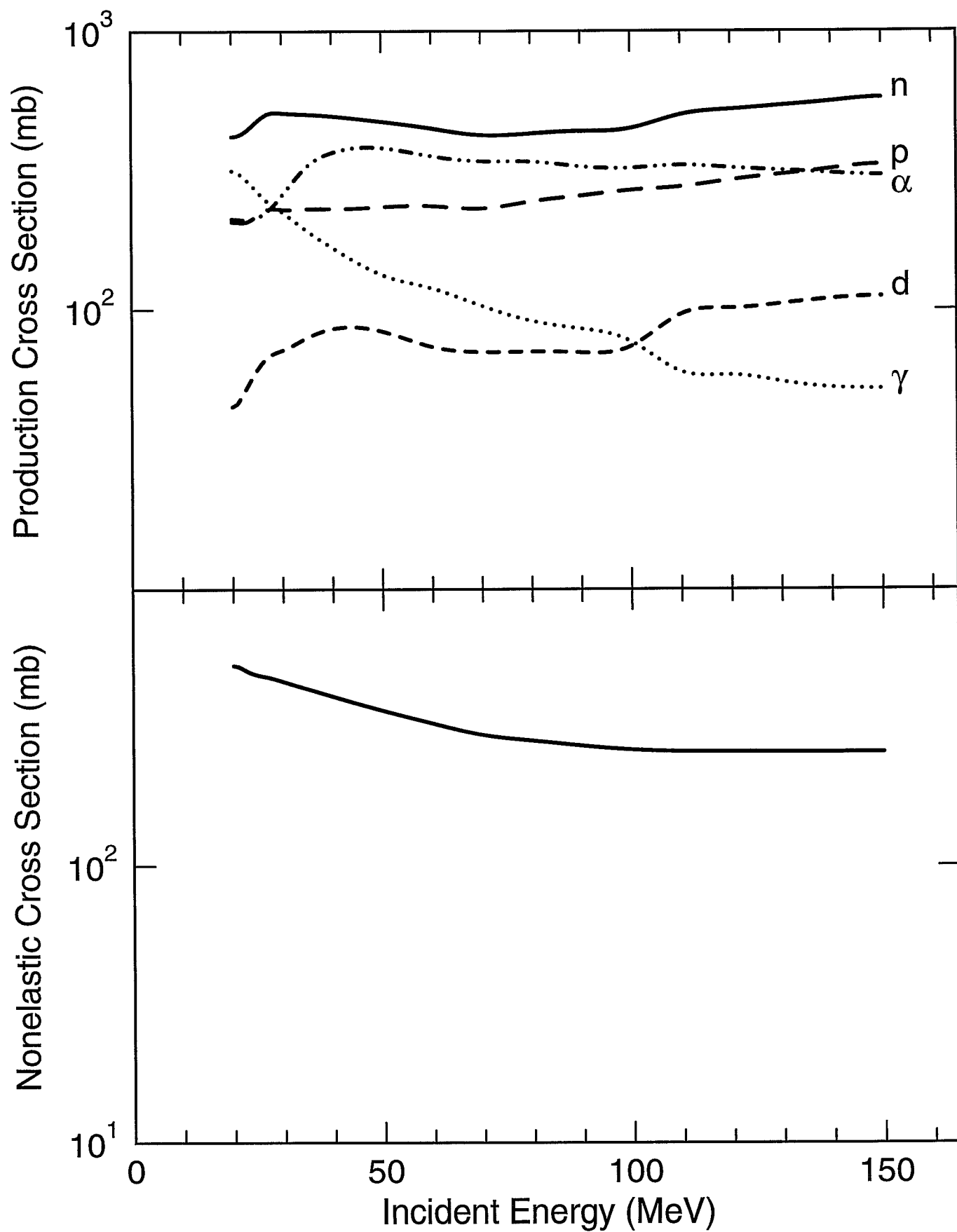| Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
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2.300E+01	5.040E-01	9.610E-01	4.403E-01	2.066E-01	5.275E-02	0.000E+00	0.000E+00	2.099E-01	2.912E-01
2.700E+01	4.819E-01	9.541E-01	5.038E-01	2.286E-01	6.724E-02	0.000E+00	0.000E+00	2.246E-01	2.457E-01
3.000E+01	4.649E-01	9.291E-01	5.084E-01	2.288E-01	7.140E-02	0.000E+00	0.000E+00	2.565E-01	2.247E-01
3.500E+01	4.365E-01	8.845E-01	5.026E-01	2.300E-01	7.937E-02	0.000E+00	0.000E+00	3.264E-01	1.922E-01
4.000E+01	4.100E-01	8.390E-01	4.950E-01	2.299E-01	8.538E-02	0.000E+00	0.000E+00	3.664E-01	1.676E-01
5.000E+01	3.646E-01	7.024E-01	4.726E-01	2.337E-01	8.362E-02	0.000E+00	0.000E+00	3.804E-01	1.334E-01
6.000E+01	3.270E-01	5.970E-01	4.469E-01	2.355E-01	7.353E-02	0.000E+00	0.000E+00	3.559E-01	1.191E-01
7.000E+01	2.971E-01	4.909E-01	4.230E-01	2.306E-01	7.033E-02	0.000E+00	0.000E+00	3.405E-01	1.033E-01
8.000E+01	2.830E-01	4.100E-01	4.285E-01	2.443E-01	7.055E-02	0.000E+00	0.000E+00	3.392E-01	9.118E-02
9.000E+01	2.710E-01	3.400E-01	4.368E-01	2.558E-01	7.003E-02	0.000E+00	0.000E+00	3.256E-01	8.536E-02
1.000E+02	2.620E-01	2.880E-01	4.466E-01	2.676E-01	7.362E-02	0.000E+00	0.000E+00	3.216E-01	7.675E-02
1.100E+02	2.582E-01	2.408E-01	4.999E-01	2.754E-01	9.599E-02	0.000E+00	0.000E+00	3.292E-01	5.983E-02
1.200E+02	2.578E-01	1.962E-01	5.224E-01	2.911E-01	1.010E-01	0.000E+00	0.000E+00	3.223E-01	5.815E-02
1.300E+02	2.571E-01	1.649E-01	5.393E-01	3.051E-01	1.046E-01	0.000E+00	0.000E+00	3.156E-01	5.506E-02
1.400E+02	2.568E-01	1.422E-01	5.578E-01	3.193E-01	1.091E-01	0.000E+00	0.000E+00	3.084E-01	5.241E-02
1.500E+02	2.568E-01	1.202E-01	5.749E-01	3.311E-01	1.112E-01	0.000E+00	0.000E+00	3.030E-01	5.183E-02

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   1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:
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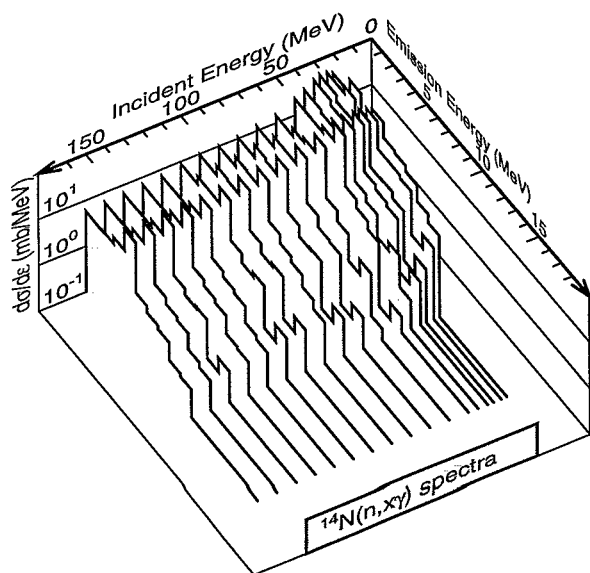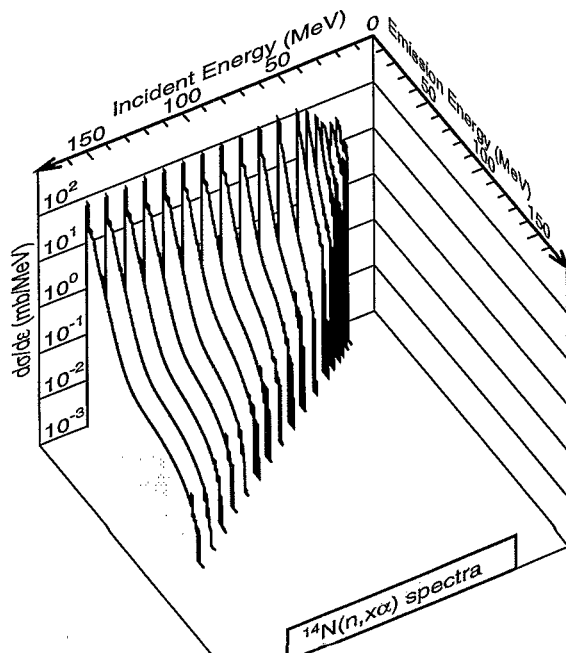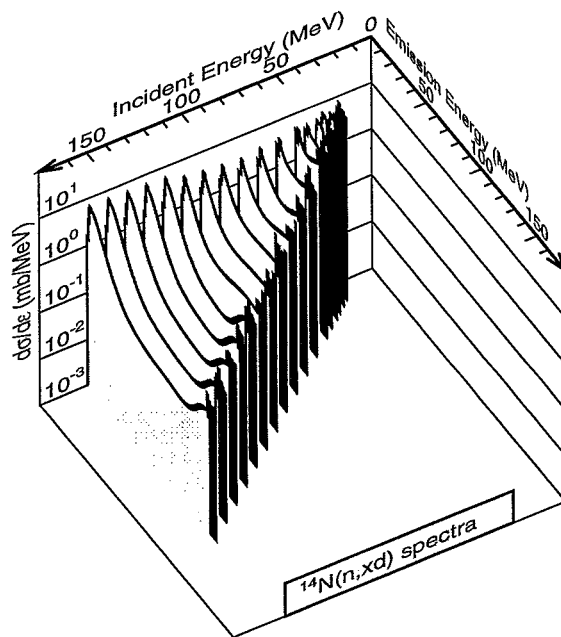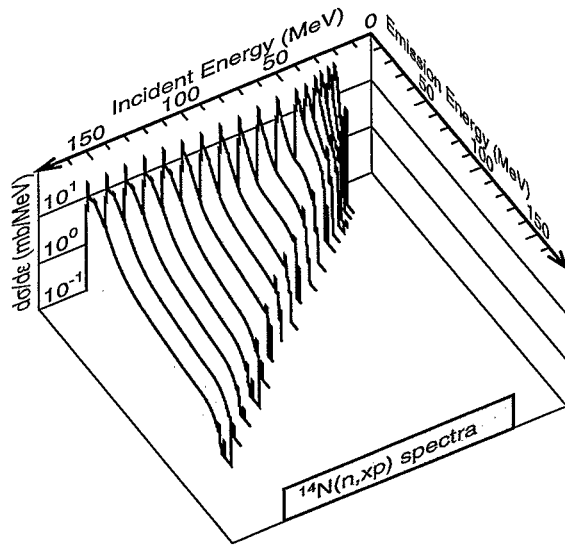
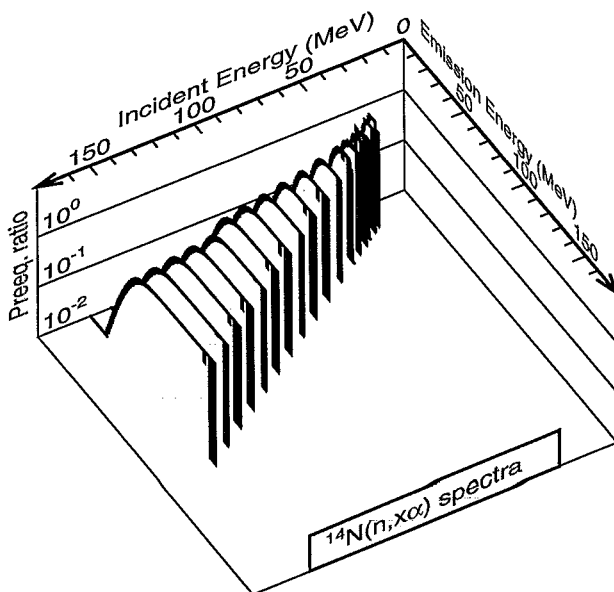| Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
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2.300E+01	6.807E-01	2.741E-01	0.000E+00	0.000E+00	9.211E-01	6.749E-01	3.616E-01	2.912E+00
2.700E+01	8.696E-01	3.971E-01	0.000E+00	0.000E+00	7.616E-01	7.123E-01	3.435E-01	3.084E+00
3.000E+01	9.811E-01	4.901E-01	0.000E+00	0.000E+00	8.306E-01	7.043E-01	3.248E-01	3.331E+00
3.500E+01	1.235E+00	6.745E-01	0.000E+00	0.000E+00	9.915E-01	6.654E-01	2.975E-01	3.864E+00
4.000E+01	1.406E+00	8.818E-01	0.000E+00	0.000E+00	1.115E+00	6.307E-01	2.754E-01	4.309E+00
5.000E+01	1.886E+00	1.110E+00	0.000E+00	0.000E+00	1.151E+00	5.511E-01	2.262E-01	4.924E+00
6.000E+01	2.371E+00	1.145E+00	0.000E+00	0.000E+00	1.188E+00	5.279E-01	1.932E-01	5.425E+00
7.000E+01	2.740E+00	1.268E+00	0.000E+00	0.000E+00	1.271E+00	4.905E-01	1.369E-01	5.906E+00
8.000E+01	3.116E+00	1.379E+00	0.000E+00	0.000E+00	1.371E+00	4.751E-01	1.118E-01	6.453E+00
9.000E+01	3.540E+00	1.435E+00	0.000E+00	0.000E+00	1.416E+00	4.694E-01	9.133E-02	6.952E+00
1.000E+02	3.902E+00	1.531E+00	0.000E+00	0.000E+00	1.479E+00	4.488E-01	7.649E-02	7.438E+00
1.100E+02	4.087E+00	1.839E+00	0.000E+00	0.000E+00	1.606E+00	4.114E-01	6.339E-02	8.007E+00
1.200E+02	4.673E+00	1.936E+00	0.000E+00	0.000E+00	1.635E+00	4.074E-01	5.123E-02	8.703E+00
1.300E+02	5.268E+00	1.960E+00	0.000E+00	0.000E+00	1.681E+00	4.063E-01	4.272E-02	9.358E+00
1.400E+02	5.831E+00	1.984E+00	0.000E+00	0.000E+00	1.709E+00	4.117E-01	3.651E-02	9.972E+00
1.500E+02	6.446E+00	1.969E+00	0.000E+00	0.000E+00	1.724E+00	4.195E-01	3.053E-02	1.059E+01

n+^{14}N nonelastic and production cross sections

n + ^{14}N angle-integrated emission spectra

^{14}N(n,xn) spectra

^{14}N(n,xp) spectra

^{14}N(n,xd) spectra

^{14}N(n,xα) spectra

^{14}N(n,xγ) spectra
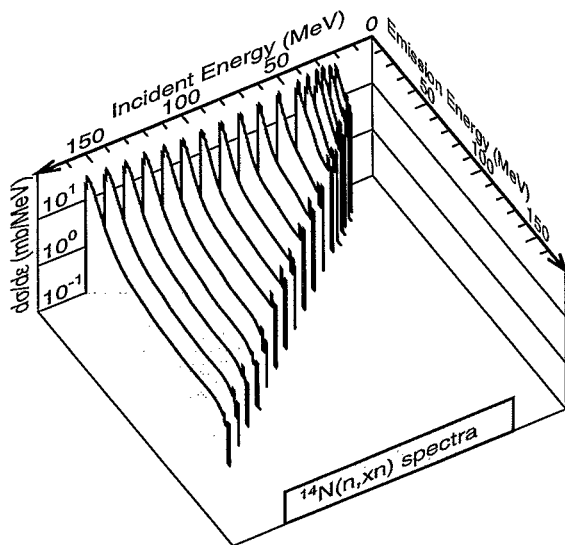
n + ^{14}N Kalbach preequilibrium ratios

^{14}N(n,xn) spectra

^{14}N(n,xp) spectra

^{14}N(n,xd) spectra

^{14}N(n,xα) spectra
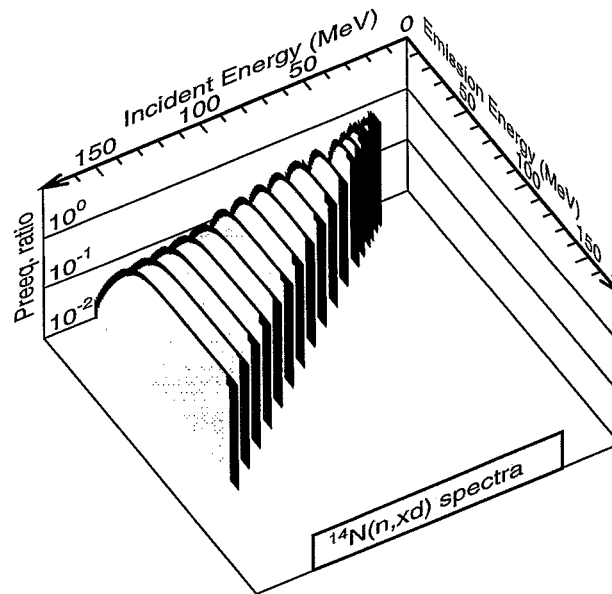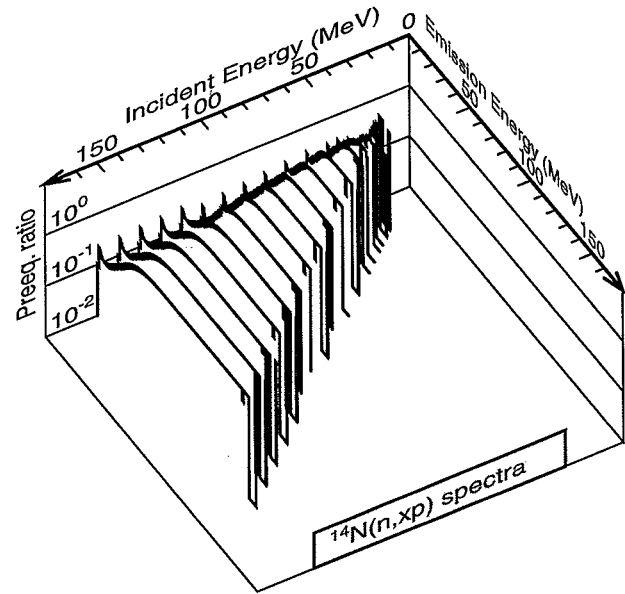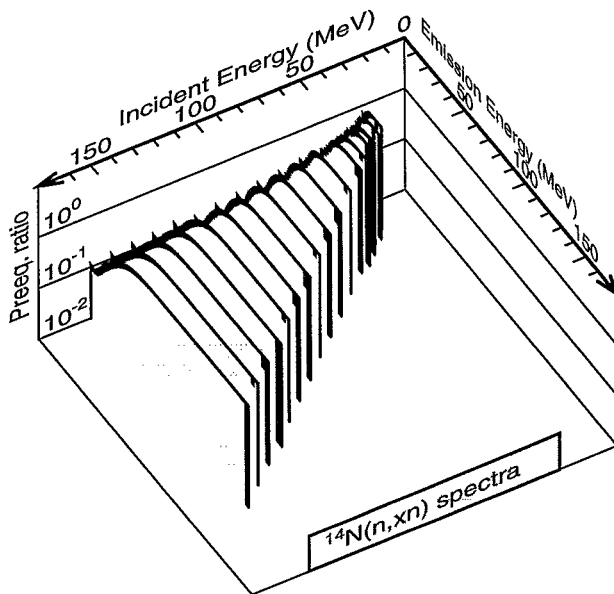
7-N-14 APT LA150
angular distribution for elastic

ProbICos

Cosine

Energy (MeV)

7-N-14 APT LA150
Heating

heating

7-N-14 APT LA150
Damage

damage